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Comparison of different methods of installing mini data loggers in high mountain ground; a contribution to the study of the periglacial environment

The temperature conditions on the first meters of the subsoil are elementary in the study of geocrology, which studies the terrestrial surface that is below 0 °C and deals with the environment and the ecology of the cold regions, as well as the processes related to the freezing and thawing cycle, with permafrost and at the same time these with human activities (Trombotto et al., 2014). Consequently is known as periglacial to that cold non-glacial environment and the processes that are generated in it, considering permafrost as a central element, although its presence is not strictly necessary (French, 2007). According to this author, permafrost is defined as soil and rock that remain at 0 °C or below this temperature for at least two continuous years.

There are indirect and direct methods to determine the presence of permafrost. The indirect ones are based on the identification of certain processes or geoforms that do not always guarantee the presence of ice inside them, which makes them less reliable. Among the direct methods are the excavations and the extraction of nuclei, as well as the recording of ground temperatures at different depths (Etzelmüller et al., 2001) since they are strictly associated with the thermal regime of the ground (Heginbottom et al., 2012). Additionally, the temperature data provide a more accurate idea about its conservation status (Serrano et al., 2009), both in circumpolar regions (Matsuoka et al., 1990, Matsuoka, 2011) and mountains in mid-latitudes (Haeberli et al., 2006; Gruber and Haeberli, 2009).

Based on the thermal conditions of the ground, there are various types of devices in the market for reading and storing the data, some more complex than others, such as micro-stations with solar panels to ensure long and uninterrupted data series; an example of these is found with Kim et al. (2005). Its disadvantage, beyond the high financial cost it represents, is that it requires constant vigilance or robust protection to prevent vandalism. There are also simpler and discrete autonomous sensors with an external thermometer. Its advantage is given by a lower price and size. Although several units are required depending on the depths to be analyzed. And to prevent the storage device from being damaged by natural or human factors, it is necessary to protect it; so if more than two units are used to monitor a single profile, a medium-sized container is commonly needed, which due to its size could attract people's attention, exposing itself to the possible loss of all devices. Therefore, the most practical, simple and economical methods is the use of mini data loggers with internal temperature sensor (Etzelmüller, 2013). Due to its size characteristics and low cost, have been used in various regions of high mountain in Europe and Latin America, being the works of Janke et al. (2011) and Trombotto (2007) respective examples of the above. Due to its low price and size of just 2-5 cm per side on average, can be distributed to cover large areas of study, as well as in different topographic conditions (Hoelzle et al., 1999) such as the mountains (Teles-Vieira et al., 2000). In turn, the resistance of their materials (Hoezle et al., 1999) allows them to be placed directly inside the subsoil without the humidity and the weight of the soil above affecting them. However, due to its size and the cementation caused by seasonal or permanent ice of the ground, its extraction can be unsuccessful, causing with this the possible loss of the devices and the stored data series.

There are several works with mini data loggers to obtain ground temperatures at different depths. At the same time, in order to avoid its loss, the conditions for installing them are also varied. Some researchers perform their placement directly in contact with the ground or rock, which is a record of temperature more true to reality, but with the risk of loss that this entails; among them: Guglielmin et al. (2003); Hoezle et al. (2003); Hanson and Hoelzle (2005); Isaksen et al. (2008); Janke et al. (2011); Hipp et al. (2014). Others, with the purpose of protecting them and achieving an easy extraction, introduce them into PVC pipes totally sealed to prevent the infiltration of humidity and air; among them are Trombotto (2007); Abramov et al. (2008); Osterkamp and Jorgenson (2009); Goyanes et al. (2014). This method is suggested in the "Manual for Monitoring and Reporting on Permafrost Measurements" of the International Permafrost Association (IPA, 2008). Trombotto and Barzotta (2009), who perform perforations of 1 cm in diameter at the height of each sensor to achieve greater interaction with the soil, use a variant of the previous method. On the other hand, the "Manual on Periglacial Field Methods" of the IPA (Humlum and Matsuoka, 2004), recommends protecting them individually in small plastic containers, without specifying the dimensions or characteristics of the material from which they should be manufactured.

In most of the works on the thermal regime of the ground, some researchers limit themselves to indicate the depths in which the sensors are placed without mentioning the technical characteristics of the same nor the system of installation that they use. The justification for the use of one method or another is not mentioned and there is no reference to the probable existence of variations in the records between the different placement options. Neither has any comparative study been found in the literature analyzing the possible temperature differences that could exist when placing sensors of similar characteristics between one installation system and another, which could mean important differences when interpreting the data.

For the above, the objective of this work is to identify possible temperature differences that are registered through the use of mini data loggers of identical characteristics, all performed in the same site, at the same time, in equal periods of time but under four different installation methods. It is expected, therefore, that this analysis will contribute to subsequent works where the topic of ground temperature, especially those that are subject to a certain degree of freezing, whether seasonal or permanent, is a central issue for the study of high mountain ecosystems and the periglacial environments.

The aim of this study was to compare three alternative methods of installing sensors against the method of direct contact with the substrate, which, as previously commented, offers records that are more real because there is no means to intervene between soil and sensors.

The sensors used were of the model Hobo Pendant® UA-001-64 of the manufacturer Onset, with an accuracy of ± 0.5 °C completely new and with 100% battery charge; each of them was calibrated from the factory. Hipp et al. (2012), have successfully carried out the use of mini sensors with these characteristics of precision for recording air temperature, snow and subsoil temperature. In the same way, Karunaratne and Burn (2004) use them for air and soil. More specifically, the sensor model used for this exercise has also been used for different environmental studies: Goulsbra et al. (2009), Núñez-Cruz and Bonfil (2013), Sanusi and Ahmad-Zamri (2014), Benvenuti and Pardossi (2016) among others.

To make the comparative measurements, the timberline was chosen at 4,050 meters above sea level (msnm) on the northern slope of the Citlaltépetl volcano (Mexico), with coordinates ϕ 19 ° 04.346'N and λ 97 ° 16,491'O. To performance this work, a clear surface was chosen, very horizontal and with a homogeneous texture soil, free of direct interaction with the vegetation and surface runoff, as well as away from the pass of mountaineers and nearby inhabitants. In it, four boreholes were drilled in line from east to west with a separation of 0.5 m between each, with a diameter of 15 cm and depth of 120 cm. The granulometry found during drilling varies from fine semi-compacted tephra in the first 20 cm, to 0.5 to 2 cm in diameter in the lower part, with some isolated fragments of larger rocks. Special care was taken not to alter the excavated material as much as possible and then fill in the boreholes in the extracted order.

First, from west to east, a 120 cm PVC hydraulic pipe with a 40-gauge wall thickness was inserted and sealed at the bottom. In its upper part, a coupling with internal thread was placed in which a threaded plug of 1 cm thickness was introduced to seal it and at the same time allow it to be opened when necessary. All PVC material used was white color to prevent the absorption of radiant energy. A line of fishing line with the same length of tube and with enough thickness to support the weight of the sensors attached to it was lashed below the threaded plug and at the center. Adjacent to pipe 1, a second pipe with the same characteristics as the first one was inserted, but with the difference that two opposite holes of 1 cm diameter were drilled in it, at the height of the center of each sensor. Attached to the wire, the mini sensors were placed in the following depths: -5, -30, -60 and -120 cm. Both screw caps were sealed until after the experiment was finished. A thin layer of soil was superimposed over each plug to avoid direct radiation from the sun. In the third borehole were introduced four commercial plastic "Tupperware" containers with dimensions of 9 × 7 × 4 cm made of polypropylene (PP) with a density of 0.95gr / cm^3 and with hermetic seal of low density polyethylene (LDPE) in the top. They were placed at the same depths in which the sensors of the pipes were installed. In each container, a mini sensor was introduced and sealed hermetically under pressure. It was ensured that the characteristics of the materials, both of the tubes and of the individual containers, were generic and universally common, as well as easy to acquire in the market. Above each container was filled with the extracted material taking special care in the order and compaction of the material. Finally in borehole number four the sensors were introduced at the same depth as in the previous three cases but this time without any material that would isolate it from direct contact with the subsoil material. The sensors were tied from its upper part to a line of thread that in turn was attached to a stake to prevent its loss. For all cases, the sensors were programmed to obtain data for one year at intervals of one hour, beginning at zero hours on July 1, 2015 and ending on June 30, 2016. Once the record year was completed, all the sensors were removed and it was verified that within the tubes and individual containers there was no presence of water or sediments.

The daily, monthly and annual average temperature for each of the installation methods was obtained from each of the depth levels. In order to preserve the highest possible accuracy in the data obtained, the three decimal places that the sensors registered were respected. The final values were tabulated and identified by groups to proceed to make the statistical comparisons and results. In the statistical tests, an analysis of variance was initially performed to compare significant differences between the means of each group considering only the installation method (ANOVA 1). In the second instance, the depth factor was included in the analysis, so the two-factor analysis of variance test (ANOVA 2) was applied. Subsequently, given that it is sought to compare the records of alternative methods against the direct method, simultaneous tests were carried out using Dunnett test, considering the direct method as a control and comparison group. A fourth test consisted of analysis of variance with repeated measures to compare the groups between pairs of possible combinations (RM ANOVA). Finally, the regression lines as well as their respective regressive equations were compared and the correction method was proposed to homologate the values that were statistically different from those of the reference group.

According to the statistical summary and the dispersion of the data with respect to their mean, that of group 2 shows very similar values in their standard deviation with respect to the reference group (group 1). The data are distributed more symmetrically within group 4 after the control group, while in group 2 the distribution is more loaded towards the lower values of the mean. However, the kurtosis curve shows that group 3 data are more concentrated around their mean value. Based on the analysis of ANOVA 1 (with a level of significance $\alpha = 0.05$) $p = 0.652560608$, it is forced to accept the null hypothesis, since there is no statistically significant difference between the methods compared. Therefore, the dispersion of the data and their means between each group are comparable to that of the remaining groups and as a consequence with those of the control group.

In the previous test, the general characteristics of each group were revised according to the distribution of their data as if they were linear values, which are obtained at a single depth to analyze their distribution. However, because the temperatures were obtained at four depth levels, it was necessary to verify their behavior in each of the soil strata. Firstly, after the execution of the ANOVA 2 test, considering both the type of installation as well as the depth of the readings, with a p value = 0.63327223, it is obtained once again that there is no statistically significant variation of temperature between depth levels. In the same way, it is obtained that the depth has the same effect in the four groups, there being no significant difference between them. Finally, interaction effects between depth and temperature were not found either.

Applying Dunnett's test, which compares once again the means of each group and their confidence intervals against those of the control or reference group (group 1), it is obtained that the data means are not significantly different from the group 1 mean because all the intervals cross at zero. Regarding the population means of each group and the dispersion of their data, an analysis of variance test with repeated measures (MR ANOVA) was carried out this time, through which, with a confidence level of 0.95, both tests multivariate comparisons between peers do not indicate a significant difference either.

Up to this point and based on the data variance tests, no statistically significant differences were found between the data groups that allow rejecting the null hypothesis, so according to the above, it would not represent a great difference at the time of use an installation method different from group 1. However, when the data and its distribution are graphically represented, different behaviors are visualized through the trend lines, both in intercepts and on slopes; therefore, an analysis comparing the regression coefficients of each group was required. In order to simplify the graph and considering that there is no difference at the time of data processing, the annual averages were calculated for each level of depth. By performing the comparative analysis of the regressions, we obtained that methods that include tubes, whether sealed or perforated, are affected by the heat energy stored in the first few centimeters of the soil surface that probably interacts with the thickness of the plastic cover that covers them, giving a higher temperature response its top part. However, the perforated pipe seems to adjust to real temperatures at greater depth due to the perforations that facilitate a better soil-sensor interaction. However, it is important to mention that this system of perforated tubes may not be appropriate in environments with ice-rich permafrost, such as that of the circumpolar regions; since the water, product of the summer thawing of the active layer, can seep inside the pipes, causing its winter refreezing to make it impossible to extract the contained sensors. It is concluded, therefore, that for the case of subsurface thermal monitoring, up to approximately one meter deep, the use of the sealed tube could be the best option, while for deeper readings and in a dry permafrost environment (French, 2007), it is advisable to use a perforated tube, in both cases, with the smallest possible diameter. We have also proposed a methodology for correcting data differences obtained through different installation methods.